

Simulation of Regional Freight Movement on the TTMNet: Trade & Transportation Multi-Networks

Jinghua Xu (Correspondent)

Research Assistant

University of Massachusetts

Department of Civil and Environmental Engineering

141 Marston Hall

Amherst, MA 01003-9293

Phone: (413)-5453852

Fax: (413)-5459569

E-mail address: jinghuax@acad.umass.edu

Kathleen L. Hancock

Associate Professor

University of Massachusetts

Department of Civil and Environmental Engineering

216 Marston Hall

Box 35205

Amherst, MA 01003-9293

Phone: (413)-5450228

Fax: (413)-5459569

E-mail address: hancock@ecs.umass.edu

Frank Southworth

Oak Ridge National Laboratory

P.O. Box 2008

Oak Ridge, TN 37831-6206

Phone: (865)-5768153

Fax: (865)-5744888

E-mail address: sou@ornl.gov

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Abstract:

The paper describes a simulation model called TTMNet, constructed for the purpose of studying the effects of highly developed information technologies and logistic strategies (e.g., e-commerce and the real-time information) on freight transportation. TTMNet is formulated as a multi-level product supply chain system that integrates the financial, informational, logistical, and physical aspects of transportation networks, with interactions between each of these networks. Several simulators, including a freight traffic simulator, a supply chain decision-making simulator, and a pseudo-real-time information simulator, are involved. The freight traffic simulation is the focus of this paper. As part of this simulator, a learning model is set up to help decision-makers estimate transportation cost based on past experiences. Given the stochastic nature of these transportation costs and of the freight demands simulated by the system, the route for an origin-destination shipment may not remain optimal during a trip, and may change along the way. A vehicle redirection procedure is presented to handle this. A numerical example is designed to compare a set of freight movements under two scenarios, one supported by and the other not supported by pseudo-real-time information on traffic conditions.

1. BACKGROUND

Freight transportation plays a vital role in the United States economy. More than 6 million business establishments in the United States rely on the nation's interconnected network of transportation services as they engage in local and interstate commerce and international trade (1). Freight movements currently account for 28% of all vehicle miles traveled and 4% of transportation related expenditures and revenues. In 1997 this was equivalent to some 13.8 trillion ton-miles of freight activity within the United States borders (2), passing over much of the nearly 4 million miles of roads, 170,000 miles of railroads, 26,000 miles of inland and coastal navigable waterways, and into and out of some 5,000 public-use airports (3). From 1998 to 2020, US domestic freight is expected to grow at 2.9% per year, while international freight is estimated to grow at 3.4% per year (4).

Currently, information technology (IT) has been widely filtering into the freight transportation industry, accompanied by the increasing globalization of the economy. Modern forms of real time, high capacity IT are having a profound effect on the way businesses order, store, and transport goods from source to market. A key element in this change is electronic commerce (e-commerce). E-commerce has seen remarkable growth over the past five years and is projected to grow very rapidly over the coming decade. Much of this growth has resulted from the development of the Internet as a commercial medium. On-line Internet trading is now a major form of business activity, and it is likely to initiate some profound changes in both domestic and international product supply chains, and cash flows, leading to some important new patterns of freight movement.

A growing interest in intermodal and containerized forms of freight transportation requires accurate and timely information, and moreover, highly efficient transportation channels. The product supply chain is such a channel. It defines a product's flow, consists of the production firms, logistic service providers, and the customers, and is linked by materials, information and financial flows (5). Transportation is treated as part of a broad logistics enterprise that operates on such a supply chain. Integrating logistic processes is the inevitable trend in supply chains, with all participants collaborating and web-connected to achieve networked supply chain excellence at Internet speed (6).

2. PROBLEM STATEMENT

What the above developments in supply chain management ultimately imply for freight traffic volumes is currently unclear. Just-in-time (JIT) inventory systems are likely to move more inventories out of warehouses and onto the transportation system. This may save inventory carrying costs but could also lead to costly operating expenses, more intensive energy consumption, and more environmental pollution. What is more, it may also come at the expense of vehicle load factors, with many partially empty vehicles being used to make delivery deadlines. Additional empty vehicle miles of travel may be involved where real time scheduling drives the need for elaborate fleet repositioning. Conversely, an Internet-based system for auctioning off such empty vehicle space is just the sort of benefit that some new web-based information companies are now offering to shippers and carriers. The result should be increased load factors.

In addition, e-commerce may also have implications for mode choice. More accurate and real time information about products suggests greater demand in the future for the faster modes of transport --- notably express air and truck. These are also, generally, the higher cost modes, so that their adoption will be based on the overall logistics costs involved in meeting market demands. Better information on the status of a particular shipment in the supply chain may also allow better coordination across the different modes, thereby encouraging more use of intermodal transportation options. To fully address these issues in modeling all of the major decisions involved in moving freight within today's business world, the authors have developed a prototype methodology that links logistics, transportation, cash and knowledge-based information flows within a single, multi-level "supernetwork" approach to enterprise-wide supply

chain modeling. Given the considerable complexity of the problem, extensive use is made of micro simulation to analyze the interactions of decision-making processes among each of these systems, with the aim of capturing the influence of each process on the resulting volume as well as pattern of freight movements.

3. LINKS TO PAST LITERATURE

A literature review identified no prior work on the construction of such an integrated analysis system as the one proposed above. When freight movements are modeled within the transportation planning process, they tend to be handled in a piecewise and very partial fashion, usually through regression analyses geared to estimating how much freight is being created and moved between places and by what means (modes), with occasional use of the full “four step” analysis framework used in metropolitan area transportation planning (i.e. trip generation, distribution, mode split and traffic route assignment) (1,7). Efforts to extend or adapt this planning model paradigm to incorporate more behaviorally sound models of freight operations have been limited (8), although work has begun in a number of places to incorporate specific aspects of freight logistics and the new, information rich economy into the transportation planning process (9). Missing from all past studies has been the in-depth treatment of transportation costs and demands within the broader context of the business logistics environment in which freight shipments are arranged and eventually transported. To advance the current study, however, aspects of a number of past studies were usefully incorporated within the modeling framework. In particular, the framework benefited directly from past work in the routing of freight over intermodal networks by Southworth and Peterson (10); from the development of multi-layered “supernetworks” which combine the representations of physical transportation network infrastructures and flows with network based representations of travel choices into a unified demand-supply modeling framework, notably by Nagurney et al (11, 12), and Sheffi (13); from the micro-simulation modeling of real time traffic over intermodal networks, notably by Febbraro et al (14); and from the modeling of stochastic and dynamical transportation systems, notably by Nagurney et al (12) and Cascetta (15).

4. THE TTMNet APPROACH

The objective of the work described below is to construct a regional freight traffic simulation system, called TTMNet, that integrates the physical components of transportation network, with appropriate components of the broader business logistics network, financial network, and information network, using micro simulation and GIS tools to address freight transportation problems within a much broader decision-making and policy sensitive environment than has previously been attempted (11). Figure 1 provides a graphical representation of the TTMNet approach.

The remaining part of Section 4 and Section 5 describe the major components of, and steps involved in TTMNet simulation modeling process. Section 6 then provides a more detailed description of one of the major components of TTMNet, the Freight Traffic Simulator. In Section 7 of the paper this simulator is used to demonstrate how TTMNet models the effects of real time information on freight traffic routing and journey times. Section 8 summarizes the major contributions of the modeling approach.

4.1 Physical Transportation Network

The physical transportation infrastructure as represented in TTMNet is constructed in the form of a single, analytically tractable, multimodal origin-to-destination (OD) routable network (10). Individual modes (truck, rail, water) are linked together in this network at selected intermodal terminals, which are also represented within the network as intermodal terminal “links”. Information such as distance, travel time, and capacity, is attached to each link in this network, allowing inter-modal as well as single mode routing of freight traffic.

4.2 Logistics Network

The logistics network models the supply-driven product flows from one facility to another, with freight moving from raw material sources to manufacturing plants, then on to distribution centers/warehouses and/or retailers, and from there to final demand markets (i.e. customers), under the objectives of minimizing total transaction costs and maximizing satisfaction of product demands involved at each stage.

4.3 Financial Network

The financial network models the market-driven payments (i.e. cash flows) for product purchases. The structure of the financial network is exactly the same as the logistics network, except that the flows move in the opposite direction, starting with payments from final customers to retailers and from retailers to manufacturers, and finally, from manufacturers to their raw materials suppliers (11).

4.4 Information Network

The information network is set up for the convenience of providing real time information required by the other individual networks. In the context of TTMNet, this information involves product demands, transaction costs in the financial and logistic networks, travel times on each transportation link, and incidents (e.g., vehicle crashes) that induce variability in travel time. Under the assumption that the simulation environment is stationary, product demands driven by market price, transaction costs, travel times, and incidents are simulated by drawing characteristics from suitable statistical distributions (e.g. a travel time distribution has a mean travel time for a particular network link plus an observed variance around that travel time).

4.5 TTMNet Representation

Figure 1 shows the links between the financial, logistics, transportation, and information networks as modeled in the TTMNet. Information flows between individual networks are shown in the form of two-way communications (i.e. as non-physical, or “virtual” links). Agents in the logistics system make decisions to order, transport, or schedule product shipments to optimally satisfy the demands they perceive, considering the state of their cash flows and the expected transaction cost for the shipments involved. Due to the stochastic nature of product demand, a dynamic OD matrix is obtained.

As an input to the freight traffic network, freight volumes in the OD matrix are dynamically assigned onto the physical transportation system based on (pseudo) real time information on travel times on transportation links. Variations in product demand will directly lead to changes in product shipments and indirectly change traffic conditions. Changes in these traffic conditions, in turn, may result in changes in transportation costs, which will influence the distribution of product shipments and may also have effects on the market prices (and so eventually, also, on the original volumes of product demanded).

In this multi-network representation, the information network not only provides the simulated (or “pseudo”) real time information to each individual network, but also keeps changing synchronously with the process of simulation.

This TTMNet framework can be applied equally to statewide, inter-regional, or even international freight movements.

5. STRUCTURE OF THE MICRO SIMULATION PROCESS

To implement the TTMNet concept, an integrated simulation system is developed. The major components of this system and their relationships are shown in Figure 2. The simulation process connects and coordinates all simulators involved, unifying them to act as one system. As shown in Figure 2, the micro-simulator is made up of the following components: Input-Output (I/O) Interface, Database, Freight Traffic Simulator (FTS), Supply Chain Decision Making Simulator (SCDMS), and Pseudo-Real-Time

Information Simulator (PRTIS). Since the designed system is modularized, additional simulators can be added or replaced as needed, providing great flexibility and applicability for freight transportation studies.

5.1 Inputs and Outputs

The I/O interface is interactive and heuristic. It accepts data in a given format and makes up the initial static information required by the simulators. It includes not only the basic information of each individual network, but also the parameter inputs of decision makers, reflecting their knowledge of the perceived network and criteria for decision making. The I/O interface also collects the outputs of a simulation session and produces a database of final results.

5.2 Database

The Database contains both static and dynamic network information. The static database consists of the structured and initialized data required by each simulator. The dynamic database records the “current” state of each individual network, updated at each event occurrence. The Database is the bridge of communication between the FTS and the SCDMS (see below).

5.3 FTS

The Freight Traffic Simulator simulates the dynamic behavior of the physical transportation network under study. It assigns the origin-to-destination shipment volumes, as estimated by the Supply Chain Decision Making Simulator (SCDMS), from the Database to the physical transportation network with the objective of minimizing total trip cost, given pseudo real time information from the Pseudo-Real-Time Information Simulator (PRTIS). Results of the FTS are used to update the database, which is subsequently used by other networks. The FTS is designed to operate as a discrete event simulation, which can be viewed as the modeling over time of a system in which states only change at discrete time instants, i.e. at those instants when events occur.

5.4 SCDMS

The Supply Chain Decision Making Simulator simulates the decision-making processes involved in supply chain management. Based on the information provided by the Database (supply chain composition, etc.) and the PRTIS (trading and network information, etc.), demands from different markets are collected. When the product demand and transaction costs are provided to the SCDMS, and based on the state of cash flow, the origins and destinations of shipments and the corresponding amount of goods are determined. The results are sent to the FTS through the updated database to implement the freight traffic assignment.

5.5 PRTIS

The Pseudo-Real-Time Information Simulator provides the pseudo real-time traffic conditions in the physical transportation network, and the pseudo real-time order and cash flow information in the logistics and financial networks, which are sent to and influenced by the FTS and SCDMS respectively.

The rest of this paper focuses on the FTS and its relationship to the PRTIS, as shown in bold in Figure 2. For details of how the SCDMS works within the overall modeling framework the reader is directed to Nagurney et al (11, 12, 16, 17), and Dong et al (18). Using the dynamic OD matrix created by the SCDMS, and stored in the database as input, freight traffic is assigned onto the physical transportation network over time, given simulated real-time information.

6. THE FREIGHT TRAFFIC SIMULATOR

The FTS simulates freight movements over the physical facilities represented by the intermodal transportation network. Travel times and occurrences of incidents on links in the network are the information required to conduct the simulation, and are both provided by the PRTIS. The types of incidents currently being considered are vehicle crashes, link constructions or closures, and inclement

weather. Pseudo real-time information, as the name implies, is not the real time information happening in the real world, but that obtained by simulating the environment and following certain generation rules. In this paper, travel time is assumed to follow the Normal distribution, while the occurrence of an incident follows the Poisson distribution. The FTS is designed to allow comparison of different freight routing (and eventually, modal selection) strategies. Therefore, the travel time on each link in every time step of the simulation, along with the timing of any incident occurrences is designed to be reproducible so that the results are comparable under different input scenarios.

6.1 Simulated Objects

Components of the system that require explicit simulation in the FTS are defined as model “objects”. In this paper, these objects consist of the network components (nodes, links, etc.) plus transportation equipment (vehicles: truck, railcar, etc.). For each object, both static and dynamic variables are used to describe its state at different discrete time intervals.

Nodes

A node models a point at the beginning or end of a link. In the physical intermodal transportation network, a node can be (1) a link connector for a single mode, (2) a terminal gate, or (3) a traffic origin or destination location. The static parameters associated with a node can be:

- Node ID.
- Links, connected by the node.
- Transportation mode(s), which can use the node.
- Terminal gate identifier.
- Cargoes, which can be handled in the terminal if the node is a terminal gate.

No dynamic variables are associated with nodes.

Links

A link, the physical connection between nodes, is characterized in the intermodal transportation network as either (1) a line haul link, (2) an access link, (3) a railroad interline (i.e. change in line ownership) link (10), or (4) a terminal link. The static parameters can be:

- Link ID.
- The pair of nodes, which the link connects.
- Link length.
- Transportation mode(s), which can use the link.
- Expected travel time, set by the system.
- Travel time deviation, set by the system.
- Direction, required when the link is not two-directional.
- Link category, which can be a line haul link, an access link, a railroad interline, or a terminal link.
- Cargoes, which can be handled on the link if the link is a terminal link.
- Operations, provided on the link if the link is a terminal link.
- Companies, who have the usage rights if the link is a railroad interline.

Dynamic variables of a link include:

- Travel time list, recording the travel times spent on the link for all previous trips in the order of their occurrence.
- Incident occurrence identifier, whose information is provided by the PRTIS.
- Estimated travel time, learned by decision makers from previous experiences.
- Estimated travel time deviation, learned by decision makers from previous experiences.
- Estimated link cost, obtained based on the formulation developed in section 6.3 below.

Transportation Equipment

Transportation equipment refers to vehicle/container types, and includes trucks, railcars, etc. It is the only type of object that can positively move among other objects simulated in the FTS. It is the critical factor causing changes of state in the TTMNet. Each piece of transportation equipment in the supply chain is characterized by the following static parameters:

- Equipment ID.
- Equipment type.
- Equipment capacity.
- Unit fuel consumption.
- Unit depreciation cost.
- Cargoes, suited for the transportation equipment to ship.

Dynamic variables associated with a piece of transportation equipment can be:

- Tonnage of the shipment, which the transportation equipment currently carries.
- Cargoes, which the transportation equipment currently carries.
- Equipment state, which can be: (a) loading or unloading, (b) running, (c) inactive, (d) stopping.
- Current location.
- Travel trajectory, recording the links that the transportation equipment has traveled as of current simulation time during the trip.
- Current route, which is the up-to-date path that the equipment is to follow.
- Time traveled, as of current simulation time by the transportation equipment during a trip.
- Distance traveled, as of current simulation time by the transportation equipment during a trip.
- Vehicle redirection quantifier.

All parameters and variables listed above make it convenient to trace and retrieve up-to-date information on each object simulated in the FTS.

6.2 Simulated Events

An event is defined as an instantaneous occurrence that can produce changes in the system state. These events describe the evolution of regional freight movement. Simulated events are classified into two categories.

Type 1: Events that describe normal traffic operation, which consist of:

- Leaving of a piece of transportation equipment at the beginning of a link.
- Arrival of a piece of transportation equipment at the end of a link.
- Initiation of loading at a shipment origin.
- Completion of loading at a shipment origin.
- Initiation of unloading at a shipment destination.
- Completion of unloading at a shipment destination.
- Initiation of an operation at a terminal.
- Completion of an operation at a terminal.
- Vehicle redirection checking.
- OD matrix updating.
- Simulation end.

Type 2: Events that describe unpredictable incidents affecting the system state, which consist of:

- Crash occurs.
- Crash ends.
- Link closure or construction occurs.
- Link closure or construction ends.

- Inclement weather occurs.
- Inclement weather ends.

Events of the first type occur following the process of simulation, while events of the second type are generated randomly by the PRTIS. Both types are associated with a corresponding operational procedure that performs the state transition resulting from the occurrence of the event. Figure 3 shows a complete freight traffic simulation flow chart, developed based on the objects and events identified above.

6.3 Transportation Cost Estimation

Transportation cost is the elementary data element required by the logistic and transportation decision-making processes. Its estimation is of great importance. In this section, only the costs generated in the FTS are studied.

Link Cost

Link cost has a positive relationship with link distance. In practice, as travel time varies, link cost varies as well. When planning a trip, variability in travel time on a link potentially increases the risk of scheduled delay of a shipment, and so induces extra cost (19). Link cost can be represented by the sum of fixed and variable costs. Directly relating to the physical distance of the link, fixed cost can be viewed as (1) the cost of fuel consumption, the depreciation of the wear and tear of vehicles along the link, or (2) the tariff or toll paid. The unit fixed cost is assumed deterministic for a certain type of vehicle and its loaded weight. Variable cost is closely associated with the travel time on the link, as estimated by decision makers. As a result, the link cost is formulated as follows:

$$LC_{ijk} = C_{ijk,f} + C_{ik,u} = c_{jk}D_i + w_k s_i + v_k \bar{T}_i \quad (1)$$

where:

LC_{ijk} : transportation cost on link i for vehicle type j in trip k ;

$C_{ijk,f}$: fixed cost on link i for vehicle type j in trip k ;

$C_{ik,u}$: variable cost on link i in trip k ;

c_{jk} : unit fixed cost;

D_i : physical distance of link i ;

w_k : unit cost induced by the estimated deviation of travel time;

s_i : estimated standard deviation of travel time on link i ;

v_k : value of estimated travel time;

\bar{T}_i : estimated travel time on link i ;

To estimate the values of s_i and \bar{T}_i , a learning process is applied to equation (1). A dynamic variable named Travel Time List is attached to a target link, and records, in time order, every past travel time on the link, as such times are perceived by decision makers. This information is used to refine the estimation of the link's expected travel time and its standard deviation. Moreover, the influence of this historical data on the estimation is not always equal but time-dependent. For example, the more recently experienced travel time contributes more to the estimation. A discount factor is set to reflect this attribute. The resulting travel time learning model can be formulated as:

$$\bar{T}_{i,t} = (T_{i,t} + gT_{i,t-1} + g^2T_{i,t-2} + \dots + g^{t-1}T_{i,1}) / \sum_{s=1}^t g^{t-s} = \sum_{s=1}^t g^{t-s} T_{i,s} / \sum_{s=1}^t g^{t-s} \quad (2)$$

$$s_{i,t}^2 = [(T_{i,t} - \bar{T}_{i,t})^2 + g(T_{i,t-1} - \bar{T}_{i,t})^2 + \dots + g^{t-1}(T_{i,1} - \bar{T}_{i,t})^2] / \sum_{s=1}^t g^{t-s} = \sum_{s=1}^t g^{t-s} (T_{i,s} - \bar{T}_{i,t})^2 / \sum_{s=1}^t g^{t-s} \quad (3)$$

where:

- $\bar{T}_{i,t}$: estimated travel time on link i at time t ;
- $T_{i,t}$: actual travel time on link i at time t ;
- $s^2_{i,t}$: estimated variance of travel time on link i at time t ;
- g : discount factor, $0 \leq g \leq 1$.

This learning model updates decision makers' perceptions of travel time based on past experiences within a certain period. When $\gamma = 1$, the travel time data experienced at each time interval is given equal weight. When $\gamma = 0$, only the most recent travel time data contributes to the estimation. However, in the case where an incident happens, the induced travel time cannot be represented by the normal situation. Moreover, an incident may exist for a certain period to influence the traffic condition on the link. Therefore, a procedure is designed for this specific situation. When an incident happens, an event that represents the end of its influential period will also be generated by the system. The travel times occurring during this time period will be recorded and used in the estimation of travel time for future trips until the end-of-the-incident event occurs, when it is removed from the list.

The above formulations for link cost are mainly for line haul links and access links, and do not apply for railroad interlines and terminal links. For a railroad interline, the link cost estimation is quite straightforward: if no agreement exists between the companies, the link cost would be infinitely large, preventing interlining; otherwise, an average cost of transferring freight from one railroad to the other is computed. For terminal links, the estimation is more complicated. A terminal link is used to connect two or more different modes, and at least one mode is restricted by its operational schedule. For simplification, the terminal link cost is assumed composed of the operational cost (such as loading and unloading cost) and a delay penalty of the time-restricted mode(s) if any.

Trip Cost

The trip cost function is the summation of the costs of all the links along the route, which is formulated as:

$$TC_k = \sum_{i \in I(k)} \sum_{j \in J(k)} (LC_{ijk} \times N_{ijk}) \quad (4)$$

where:

- TC_k : total cost for trip k ;
- LC_{ijk} : transportation cost on link i for vehicle type j in trip k ;
- N_{ijk} : number of vehicles of type j on link i in trip k ;
- $I(k)$: set of all the links passed in trip k ;
- $J(k)$: set of all vehicle types used in trip k ;

6.4 Vehicle Redirection

Links used by a shipment are selected in accordance with the estimation of the "best" route, i.e., the route of least transportation cost. Along the trip, the route for each shipment is further adjusted for any changes in the prevailing traffic conditions (e.g. incidents). Vehicle redirection, which occurs due to the perceived dynamics of traffic conditions and the randomness of incident occurrences, is a function of the transportation costs on competing routes. No explicit diversion occurs in response to the occurrence of events. Instead, only an implicit one exists when these events become the cause of the variability in transportation cost. This vehicle redirection process is assumed controlled by dispatchers and not by drivers themselves. It is a decision-making process that occurs not in the logistic network, but in the

transportation network. Once a vehicle departs from the origin, the traffic conditions on the links along the route have to be tracked frequently. Decision makers check the current traffic conditions to decide whether redirection is needed or not, and drivers are assumed to respond immediately to redirection orders.

Vehicle redirection happens not on links, but at nodes. Thus, once the target vehicle reaches a node, the checking procedure for vehicle redirection is activated. This checking procedure finds a route from the current location to the destination based on the criteria of least transportation cost. Considering the stochastic nature of the physical transportation network, it is impractical to change routes whenever a newly generated route costs less than the current one. Instead, a threshold is set to determine whether redirection is warranted or not. If the newly chosen route's cost is sufficiently smaller than the current one, the transportation equipment is redirected to the new path; otherwise redirection is not performed. Specifically, in the real time scenario, decision-makers always know the real time traffic conditions of the network. Once a vehicle reaches a node, decision-makers would find the optimal route from the current node to the destination based on the current traffic conditions. If the redirection requirement is satisfied, the route would be changed to the new one.

Among the simulated events as identified in Section 6.2, Type 1 (i.e. normal traffic) events would not directly influence the traffic conditions of the network. However, even under normal conditions, traffic characteristics still change over time due to the stochastic nature of traffic flow. The redirection threshold is therefore defined to allow room for such natural variability in travel times without causing a vehicle to alter its route. Type 2 events (i.e. unexpected incidents) would change the traffic condition by increasing the link travel time to a degree based on the severity of an incident. If the incident changes the traffic condition dramatically enough to be over the redirection threshold, then the pre-determined route is no longer optimal, and the vehicle is redirected to an alternative route.

7. SIMULATION RESULTS

The Freight Traffic Simulator (FTS) formulated in the previous sections provides a strong functionality to test the influences of various strategies on freight movements. In this section, an experiment has been designed to analyze the influences of pseudo real-time information on the behavior of freight movements. For this purpose, this experiment is conducted under two scenarios. In Scenario 1, pseudo real-time traffic conditions of the transportation network, including the current travel time on each link, and the occurrences and types of incidents, are provided once every minute, for decision makers to update their perception of the network and adjust shipment-specific trips. In Scenario 2, decision makers do not have current information of the network, except for travel times and incidents experienced by their own vehicles running on the network.

The experiment was conducted on a transportation network composed of 11,158 links within the New England and New York State areas. A set of nine freight shipments is provided for simulation under both scenarios, as this data would be provided in the full simulation modeling system from the SCDMS (cf. Figure 2). This data is composed of shipments from four freight generating origins locating in New York, Connecticut, and Maine respectively, and five freight receiving destinations, all in Massachusetts. The locations of these origins and destinations and the shipments between them are shown in Figure 4. Each origin is assumed to have vehicles readily available to transport goods, and that a single, homogeneous commodity is being shipped. The simulations under both scenarios are performed with one-day duration. The results are shown in Table 1.¹ From Table 1, we can see that the total transportation costs, travel times and travel distances of shipments in Scenario 1 are generally lower than in Scenario 2. Delay ratio, defined as the ratio of delayed freight volume to the total volume transported, is zero in the first scenario,

¹ The entire simulation process will be described in detail in the dissertation of Jinghua Xu, University of Massachusetts-Amherst, available in the fall of 2003.

while in the second scenario, approximately 19% of the freight volume was delayed. These results indicate that the simulated freight movements are better organized when real time information is provided, as decision makers are well informed of, and thus can quickly respond to, the changing traffic conditions. The route patterns under both scenarios are shown in Figure 4. From this figure we can see that most of the links used in Scenario 1 (shown as red and yellow lines) are utilized in Scenario 2 (shown as blue and yellow lines) as well; while almost half of the links used in Scenario 2 are not utilized in Scenario 1. This indicates that the routes selected in Scenario 1 are much more concentrated into a set of links of comparatively less transportation cost than in Scenario 2. In this example, then, real time traffic information has a significant effect on changing the incidence of the trucks simulated on the regional highway network. However, from the experiment, we also noticed that real time information does not always lead to superior trip planning (Shipments S4 and S6, shaded in Table 1). When an incident occurs on a link along the original route, decision makers obtain the information and redirect their vehicles in Scenario 1 because the incident causes serious congestion which increases the transportation cost above the threshold; while in Scenario 2, decision makers do not know of this situation and vehicles continue on the original route. However, the incident in this case does not last as long as decision makers predict, and traffic conditions recover quickly. If in Scenario 2 the vehicles still do not reach the location of the incident when the incident clears, i.e., the freight movement is not influenced by the incident, the non-real-time scenario would be more efficient. Therefore, to enhance the effectiveness of using real-time information, the modeling of the decision-making process being addressed needs refining to make it adaptable to a range of possible situations.

8. CONCLUSION AND FUTURE RESEARCH

In this paper a conceptual structure for a simulation model called TTMNet was introduced and described. The constructed simulation system provides a powerful tool to analyze the influences of traffic conditions on freight movements over an intermodal transportation network under various highly developed strategies. The results of this type of research can contribute significantly to an improved understanding, development, and, eventually, operation of next-generation transport systems. By providing a framework that integrates goods, information, and cash flows among organizations from point of origin to point of consumption, a more comprehensive understanding of what influences, or might be made to influence, freight movement patterns can be developed. The ultimate goal here is that of maximizing consumer satisfaction and minimizing organizational costs. The system should also provide a better, more in-depth understanding of freight movements on the physical transportation network. A key feature of this approach, and the focus of the second half of the paper, is its potential for evaluating the impact of information technologies on the over-the-road movement of freight shipments. Using two example scenarios it was shown, via micro-simulation, how real time information on highway conditions can be used to simulate realistic improvements in truck routing patterns. Placing this sort of micro-simulation within the broader TTMNet simulation system, and linking it with recent developments in the modeling of commodity flows and cash flows (11, 16, 17) now offers the potential to investigate the links between traffic congestion, its influence on transportation costs, and the effects of these costs on commodity prices and flows. To be able to accomplish this in an explicitly spatial and temporal manner, using real company data would represent a major step forward in freight flow modeling as well as shipper logistics.

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REFERENCES

1. Pendyala, R.M., Shankar, V.N., and R.G. McCullough. Freight Travel Demand Modeling: A Synthesis of Approaches and Development of a Framework. *Transportation Research Record 1725*, 2000, pp.9-18.
2. Capelle, R.B. et al. *Freight USA. Highlights from the 1997 Commodity Flow Survey and Other Sources*. Report prepared for the Bureau of Transportation Statistics U.S. Department of Transportation, Washington D.C 20590, 2000.
3. *Transportation Statistics Annual Report*. Bureau of Transportation Statistics, 1999.
4. Lambert, B. *National Freight Movements*. FHWA, Office of Freight Management & Operations, 2001.
5. Stadtler, H., and C. Kilger. *Supply Chain Management and Advanced Planning*. Springer-Verlag Berlin Heidelberg, New York, 2000.
6. Kuglin, F.A., and B.A. Rosenbaum. *The Supply Chain Network @ Internet Speed*. American Management Association, 2001.
7. Holguin-Veras, J., and E. Thorson. Trip length distributions in commodity-based and trip-based freight demand modeling. *Transportation Research Record 1707*, 2000, pp.37-48.
8. Boarkamps, J.H.K., van Binsbergen, A.J., and P.H.L. Bovy. Modeling behavioral aspects of urban freight movements in supply chains. *Transportation Research Record 1725*, 2000, pp.17-25.
9. Brewer, A.M., Button, K.J. and D.A. Hensher. (Eds) *Handbook of Logistics and Supply-Chain Management*. Pergamon, 2001.
10. Southworth, F., and B.E. Peterson. Intermodal and international freight network modeling. *Transportation Research C* 8, 2000, pp.147-166.
11. Nagurney, A., Ke, K., Cruz, J., Hancock, K., and F., Southworth. Dynamics of Supply Chains: A Multilevel (Logistical/Informational/Financial) Network Perspective. *Environment and Planning B*, 2002 (Forthcoming).
12. Nagurney, A., and J. Dong, *Supernetworks: Decision-Making for the Information Age*. Edward Elgar Publishing Inc, 2002.
13. Sheffi, Y. *Urban Transportation Networks*. Prentice-Hall, Englewood Cliffs, NJ, 1985.
14. Febbraro, A.D., Recagno, V., and S. Sacone. INTRANET: A New Simulation Tool for Intermodal Transportation Systems. *Simulation Practice and Theory*, Vol. 4, 1996, pp.47-64.
15. Cascetta, E. A Stochastic Process Approach to the Analysis of Temporal Dynamics in Transportation Networks. *Transportation Research B*, Vol.23B, No.1, 1989, pp.1-17.
16. Nagurney, A., Loo, J., Dong, J., and D. Zhang. Supply Chain Networks and Electronic Commerce: A Theoretical Perspective. *Netnomics*, Vol 4, 2002, pp.187-220.
17. Nagurney, A., and K. Ke. Financial Networks with Electronic Transactions: Modeling, Analysis, and Computations. *The 5th Conference on Electronic Commerce Research*, Montreal, Canada, Oct. 2002.
18. Dong, J., Zhang, D., and A. Nagurney. A Supply Chain Network Equilibrium Model with Random Demands. *European Journal of Operational Research* (Forthcoming).
19. Cohen, H. and F. Southworth. On the measurement and valuation of travel time variability due to incidents on freeways. *Journal of Transportation and Statistics* 2.2, 1999, pp.123-132.

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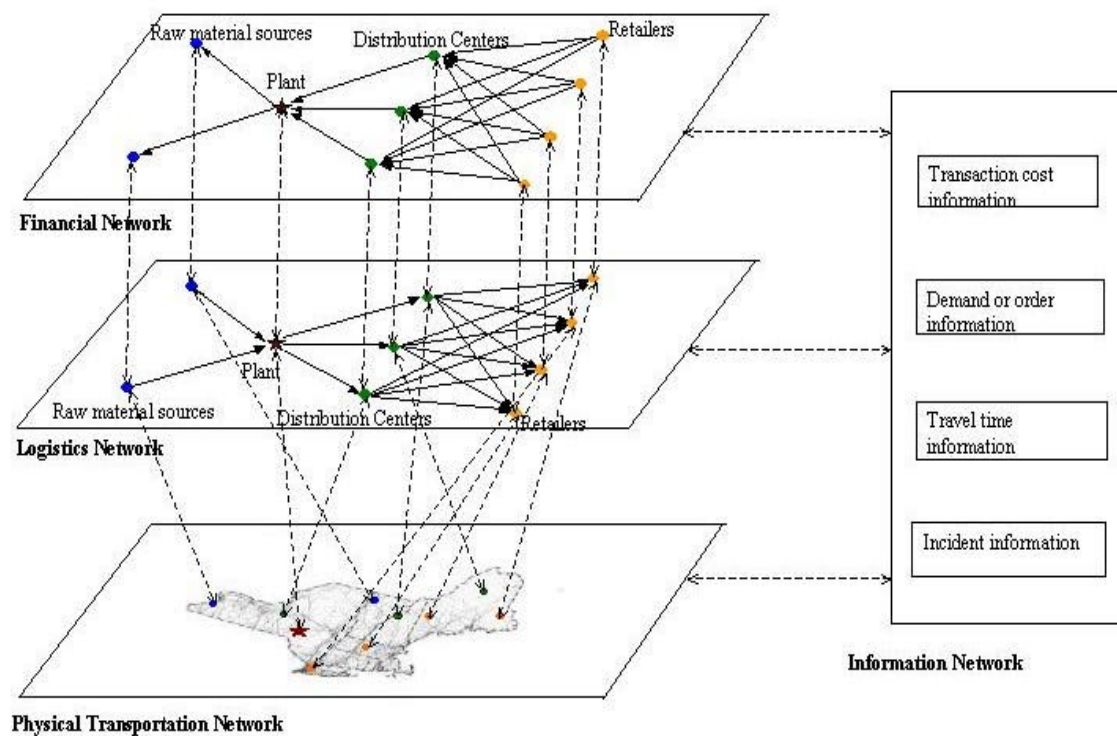
FIGURE 4 Route patterns of simulated shipments under different scenarios.

TABLE 1 Comparison of Simulation Results under Different Scenarios

Shipment No.	Total Transportation Cost (\$)			Total Travel Time (min)			Total Travel Distance (mile)		
	Scenario1: With Pseudo Real-time	Scenario2: Without Pseudo Real-time	Difference (%)	Scenario1: With Pseudo Real-time	Scenario2: Without Pseudo Real-time	Difference (%)	Scenario1: With Pseudo Real-time	Scenario2: Without Pseudo Real-time	Difference (%)
S1	140.64	148.60	-5.36	410	445	-7.87	302.97	401.37	-24.52
S2	228.65	301.15	-24.07	694	1040	-33.27	473.79	473.20	0.12
S3	83.05	85.30	-2.64	231	240	-3.75	172.69	174.54	-1.06
S4	52.14	51.61	1.03	152	149	2.01	101.22	101.76	-0.53
S5	112.97	132.96	-15.03	333	424	-21.46	292.19	308.16	-5.18
S6	178.82	172.72	3.53	606	564	7.45	353.62	364.01	-2.85
S7	205.81	218.91	-5.98	649	713	-8.98	454.61	459.88	-1.15
S8	98.32	105.94	-7.19	347	392	-11.48	230.37	241.58	-4.64
S9	103.98	129.64	-19.79	318	434	-26.73	259.03	292.17	-11.34

Delay Ratio: Scenario 1: 0; Scenario 2: 18.82%.

Note: The shaded rows highlight the shipments that are not as well organized in Scenario 1 as in Scenario 2.



Note: Each dashed arrow between networks represents the two-way information exchange between specific decision makers.

FIGURE 1 Multi-layer representation of the TTMNet.

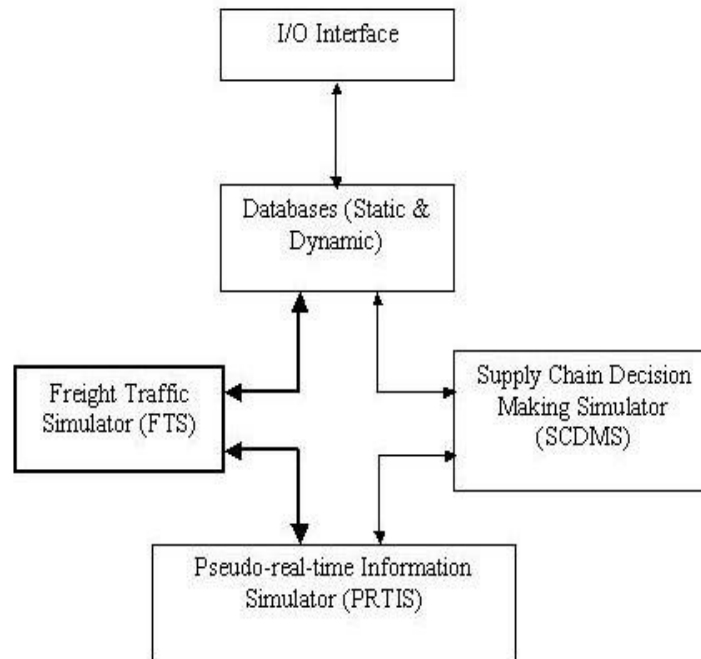


FIGURE 2 Structure of regional freight movement microsimulation.

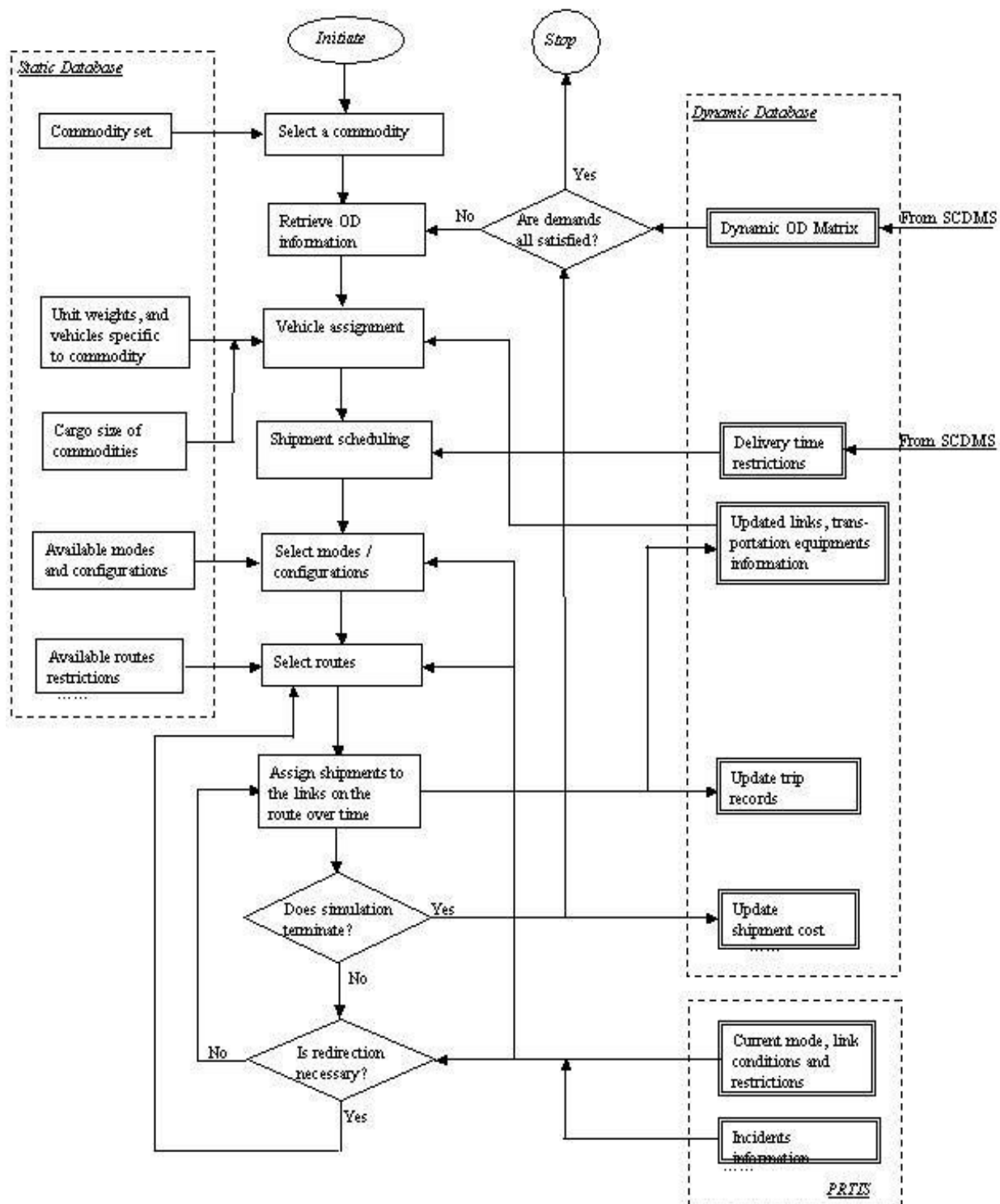


FIGURE 3 Freight Traffic Simulator simulation flow chart.

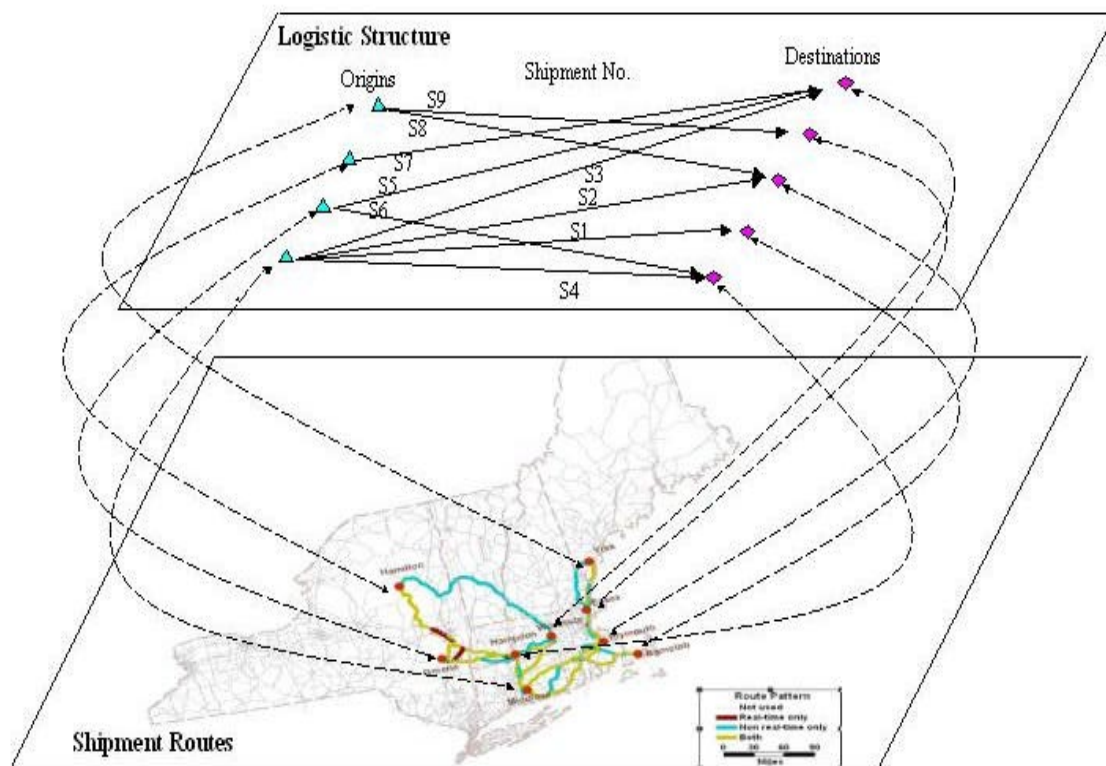


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